PC UFC Briefing
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Wood Requirements

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Wood Requirements

- This section provides the specific requirements for designing a wood building to resist progressive collapse.
- As described in the 1996 version of the *Load and Resistance Factor Design Manual for Engineered Wood Construction*, from the American Forest & Paper Association (AF&PA/ASCE 16-95), wood construction can be categorized as
  - ◊ wood frame,
  - ◊ noncombustible wall-wood joist, and
  - ◊ heavy timber.
- As most wood construction used for DoD facilities falls under the wood frame category, this is the focus of these provisions.

Wood Requirements

- Composite Construction
  - ◊ Noncombustible wall-wood joist construction, such as masonry load-bearing walls with wood floor and roof systems, is considered a composite system and requires the application of both the requirements of this chapter and those provided for masonry in Chapter 6.
  - ◊ The floor system and roof system are required to meet the internal tie requirements of this chapter, while the masonry walls are required to meet the tie (vertical, peripheral, and wall) requirements or AP requirements of Chapter 6.

Wood Requirements

- Material Properties for Wood
  - ◊ All over-strength factors for wood are equal to 1.0.
  - ◊ The time effect factor λ, shown in Table 7-2 and discussed in Appendix B of the UFC, is equal to 1.

Wood Tie Force Requirements

- Wood Tie Force Requirements
  - ◊ The following sections provide the necessary information to calculate the tie force demands for the various required ties.
  - ◊ An example showing the calculation of the required tie forces and the design of connections and elements to resist tie forces is presented in Appendix F in the UFC.

Wood Tie Force Requirements

- The British do not provide explicit Tie Force requirements for wood frame construction.
- However, the British provide some guidance for timber construction in BRE 2003, which states that: "The regulations suggest high tie forces to take account of the typical wide spacing of post and beam structures using steel or concrete materials. While these tie forces could be designed to spread through the timber frame elements it is not considered a practical option, although not impossible."

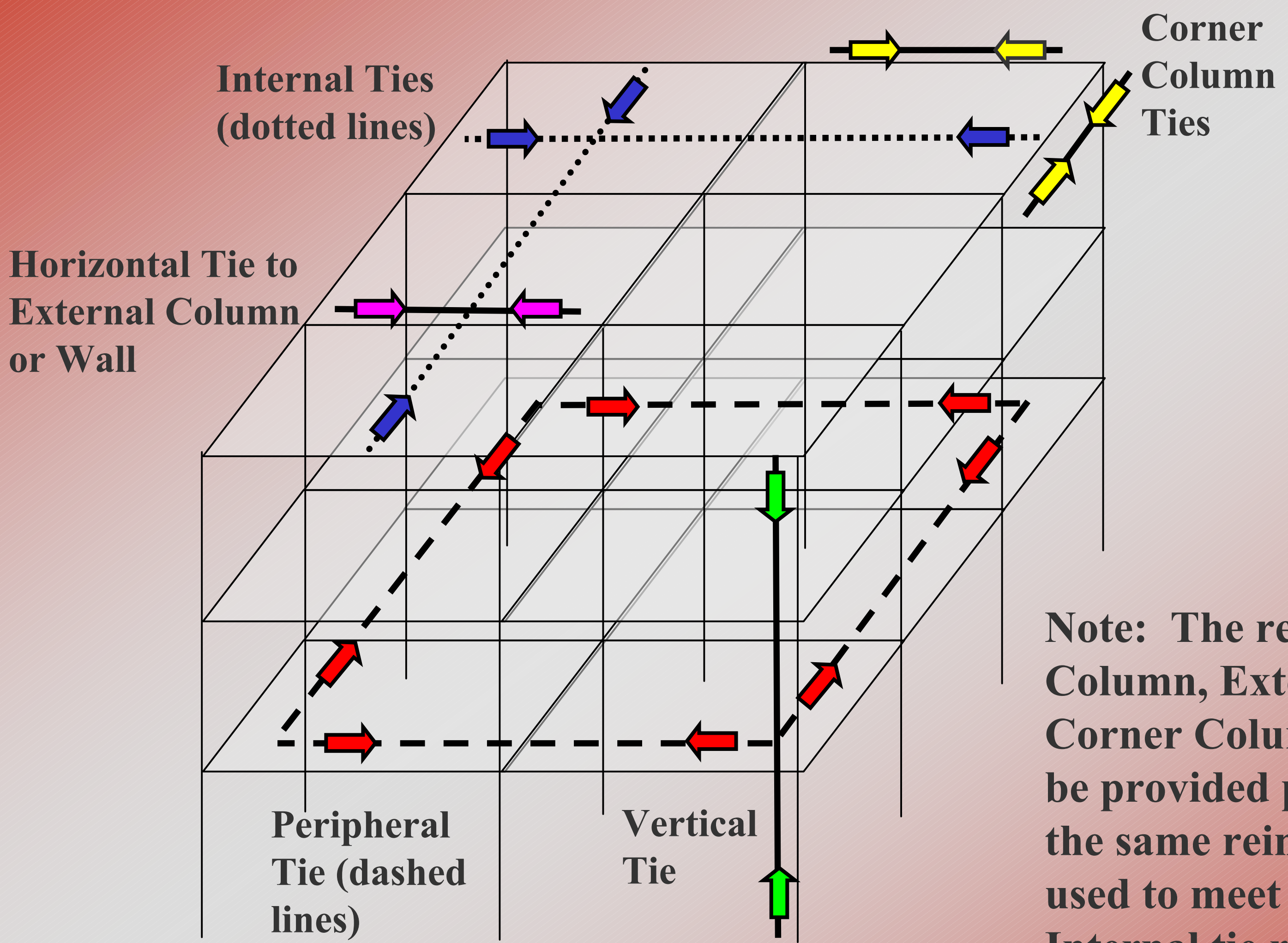
Wood Tie Force Requirements

- In this UFC, Tie Force requirements for wood frame (and cold-formed steel) are specified in a similar manner to those for reinforced concrete and masonry, since all four types of structures rely on load-bearing walls, posts, and columns and share a number of similar connection and floor configurations.
- It should be noted that BRE 2003 goes on to state that the Alternate Path method "...provides the appropriate route for platform timber frame structures" and guidance on the length of the removed members is provided.
- Additional details on Tie Forces and the AP method for wood are provided in Appendices B and E in the UFC.

Wood Tie Force Requirements

- General
  - ◊ Wood frame construction is analogous to closely spaced columns and beams with nominal tie resistance provided at each joist to wall stud junction.
  - ◊ Peripheral, internal, vertical, and horizontal ties to columns and walls are required.
  - ◊ Structural members and connections that are provided for other purposes may be regarded as forming part or whole of the required ties.
  - ◊ Ties must, whole or in part, be spread evenly in the diaphragm or must be grouped at or in beams, walls or other appropriate positions.

Wood Tie Force Requirements



Note: The required External Column, External Wall, and Corner Column tie forces may be provided partly or wholly by the same reinforcement that is used to meet the Peripheral or Internal tie requirement.

Wood Tie Force Requirements

- Strength Reduction Factor Φ for Wood Tie Forces
  - ◊ For tension members and mechanical connectors that provide the design tie strengths, use the appropriate tensile strength reduction factors Φ from AF&PA/ASCE 16-95.
  - ◊ For example, use a strength reduction factor of 0.65 for nails, spikes, and wood screws under lateral load.

Wood Tie Force Requirements

- Continuity and Anchorage of Ties
  - ◊ At re-entrant corners or at substantial changes in construction, care must be taken to insure that the ties are adequately anchored or otherwise made effective

Wood Tie Force Requirements

- Internal Ties
  - ◊ Distribution and Location
    - These ties must be distributed at each floor and roof level in two directions approximately at right angles.
    - They must be effectively continuous and must be anchored to peripheral ties at each end (unless continuing as horizontal ties to columns or walls).

Wood Tie Force Requirements

- Internal Ties, cont'd
  - ◊ Distribution and Location, cont'd
    - They must, whole or in part, be spread evenly in the diaphragm or must be grouped at or in beams, walls or other appropriate positions.
    - Spacings must not be greater than 1.5 l_r, where l_r is the greater of the distances between the centers of the frames or walls supporting any two adjacent floor spaces in the direction of the tie under consideration (i.e., approximately the span length associated with the tie).
    - In walls, they must be within 0.5 m (1.6 ft) of the top or bottom of the floor diaphragm

Wood Tie Force Requirements

- Internal Ties, cont'd
  - ◊ Required Tie Force Capacity

    In English units and in each direction, internal ties must have a required tie strength (in kip/ft width) equal to the greater of:

    a) $$\frac{(1.0D + 1.0L)}{65} \; \frac{l_r}{15} \; \frac{1.0}{3.3} \; F_t \qquad \text{(kip/ft)}$$

    or

    b) $$\frac{1.0}{3.3} \; F_t \qquad \text{(kip/ft)}$$

    where: D = Dead Load (lb/ft^2), L = Live Load (lb/ft^2)

    l_r = Greater of the distances between the centers of the columns, frames or walls supporting any two adjacent floor spaces in the direction of the tie under consideration (ft)

    F_t = "Basic Strength" = Lesser of $(1.62 + 0.33n_o)$ or 4.92

    n_o = Number of stories

Wood Tie Force Requirements

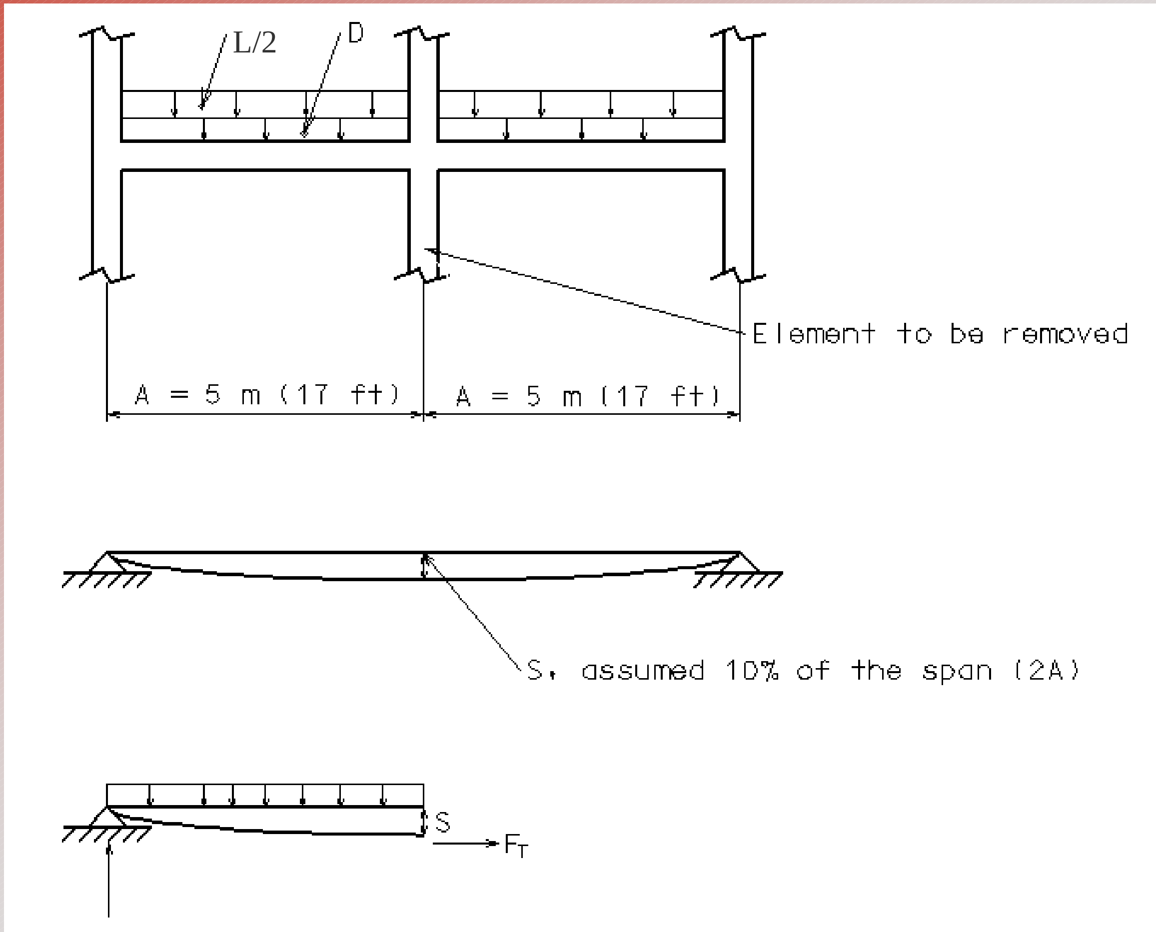
- Internal Ties, cont'd
  - ◊ Whenever walls occur in plan in one direction only (e.g. "cross wall" or "spine wall" construction), the value of l_r used when assessing the tie force in the direction parallel to the wall must be taken as either the actual length of the wall or the length which may be considered lost in the event of an accident, whichever is the lesser.
  - ◊ The length which may be considered lost must be taken as the length between adjacent lateral supports or between a lateral support and a free edge.

Wood Tie Force Requirements

- Internal Ties, cont'd
  - ◊ Background
    - As shown, internal tie force requirements for wood are specified in a similar manner to those for reinforced concrete and masonry, since all four types of structures rely on load-bearing walls, posts, and columns and share a number of similar connection and floor configurations.
    - The differences are in:
      - the values for the upper limit of F_t (the "Basic Strength"),
      - the constants in the equation defining F_t as a function of the number of stories, and
      - the scaling values for the internal tie strength in Section 7-2.4.2.

Wood Tie Force Requirements

- Internal Ties, cont'd
  - ◊ Background
    - These values are based on a similar analysis as shown in Section B-3.1.1.1 and Figure B-1.
    - In this case, typical values for American light frame wood construction were used:
      - Dead Load = 0.72 kN/m^2 (15 psf),
      - Live Load = 2.39 kN/m^2 (50 psf), and
      - Span A = 4.6 m (15 ft),
    - This yields an upper limit of F_t = 21.9 in SI units and 4.92 in English units.
    - Note that the constants in the equation for the Basic Strength as a function of the number of stories have been scaled from that for concrete and masonry, to give the correct upper limit.



$$\sum M = F_T * S = \frac{(D + \frac{L}{2})}{8} * (2A)^2$$

$$F_T = \frac{(D + \frac{L}{2}) * A^2}{2S}$$

Typical British Construction circa 1970:

A = 4.6 m (15 ft)
S = A/5
D = 0.72 kN/m^2 (15 psf)
L = 2.39 kN/m^2 (40 psf)

Thus, F_t= 21.9 kN/m (1.5 kip/ft or 4.92 kip/3.3-ft)

Wood Tie Force Requirements

- Peripheral Ties
  - ◊ At each floor level and roof level, an effectively continuous peripheral tie must be provided, capable of providing a required tensile strength equal to 1.0 F_t, located within 1.2 m (3.9 ft) of building edges or within the perimeter wall.

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Wood Tie Force Requirements

- Horizontal Ties to External Walls and Columns
  - ◊ *In English units*, each external column and, if the peripheral tie is not located within the wall, every 3.3 ft length of external wall carrying vertical load must be anchored or tied horizontally into the structure at each floor and roof level with a tie with a required tie strength (in kips) equal to the greater of:

a) the lesser of 2.0 F_t or $(l_s/8.2)\ F_t$ (kip)

or

b) 3% of the largest factored vertical load, carried by the column or wall at that level, due to conventional design load combinations (kip)

where: l_s = the floor to ceiling height (ft).

Wood Tie Force Requirements

- Horizontal Ties to External Walls and Columns, cont'd
  - ◊ Where the peripheral tie is located within the wall, provide horizontal ties adequate to anchor the internal ties to the peripheral ties.
  - ◊ Corner columns must be tied into the structure at each floor and roof level in each of two directions, approximately at right angles, with ties having a required tensile strength equal to the greater of a) or b) from the previous section.

Wood Tie Force Requirements

- Vertical Ties
  - ◊ Each column and load-bearing wall must be tied continuously from the lowest to the highest level.
  - ◊ The tie must be capable of resisting a tensile force equal to the largest factored vertical load received by the column or wall from any one story, due to conventional design load combinations.

Wood Tie Force Requirements

- Vertical Ties, cont'd
  - ◊ When a wall at its lowest level is supported by an element other than a foundation, a general check for structural integrity must be made (i.e., a careful check must be made and appropriate action taken to insure that there is no inherent weakness of structural layout and that adequate means exist to transmit the dead, live, and wind loads safely from the highest supported level to the foundations).

Wood Tie Force Requirements

- Vertical Ties, cont'd
  - ◊ Note that recent research and full scale tests on wood frame construction conducted in the United Kingdom suggest that although the development of adequate tie force capacity can be shown for wood frame construction, it may be more efficient to show the bridging of deficient vertical load-bearing elements using the AP approach.
  - ◊ Further information on the AP approach for wood frame construction is provided in Section 7-3.

Wood Tie Force Requirements

- Load-bearing Elements with Deficient Vertical Tie Forces
  - ◊ If it is not possible to provide the required vertical tie force in any of the load-bearing elements, then the Alternate Path method is applied for each such deficient element.
  - ◊ Remove each deficient member from the structure, one at a time in each story in turn, and perform an AP analysis to verify that the structure can bridge over the missing member.
  - ◊ The amount of member to be removed from the structure is given in Table 7-1.

Wood Tie Force Requirements

Removal of Deficient Wood Vertical Tie Members

Vertical Load-bearing Element Type	Definition of Element	Extent of Structure to Remove if Deficient
Column	Primary structural support member acting alone	Clear height between lateral restraints
External Wall	All load-bearing walls that form the perimeter and external face of the building but not room partitions	Length between intersecting walls (perpendicular partitions, return walls, internal room dividers), or between columns. Minimum length of wall to be considered 2.4 m (7.9 ft).
Internal Wall	All load-bearing walls within the building including room partitions	Length limited between intersecting walls or 2.25H, where H is the clear height between lateral supports (i.e. floor-to-floor).

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AP Method for Wood

- Alternate Path Method for Wood
  - ◊ The Alternate Path approach is used to verify that the structure can bridge over removed elements.
  - ◊ The general procedure provided in Section 3-2 must be followed.

AP Method for Wood

- Acceptability Criteria for Wood
  - ◊ The acceptability criteria are provided in Table 7-2 and the design strengths must be calculated per AF&PA/ASCE 16-95.
  - ◊ The subsequent actions for the AP model after violation of the acceptability criteria are detailed in the following sub-sections.

AP Method for Wood

Acceptability Criteria and Subsequent Action for Wood

Structural Behavior	Acceptability Criteria	Subsequent Action for AP Model
Element Flexure	**$\Phi\ \lambda$ M'[A]**	**Section 7-3.1.1**
Element Combined Axial and Bending	**AF&PA/ASCE 16-95 Chapter 6 Interaction Equations, Include λ[A]**	**Section 7-3.1.2**
Element Shear	**$\Phi\ \lambda$ V'[A]**	**Section 7-3.1.3**
Connections	**Connection Design Strength, Include λ[A]**	**Section 7-3.1.4**
Deformation	**Deformation Limits, Defined in Table 7-3**	**Section 7-3.2**

[A] Nominal strengths are calculated with the appropriate material properties and over-strength factor Ω. All Φ factors are defined per AF&PA/ASCE 16-95. The over-strength factor and time effect factor are both 1.0

AP Method for Wood

- Flexural Resistance of Wood
  - ◊ For wood, the flexural design strength is equal to the nominal flexural strength, calculated with the appropriate over-strength factor Ω and time effect factor λ, multiplied by the strength reduction factor Φ.
  - ◊ Calculate the nominal flexural strength per Chapter 5 of AF&PA/ASCE 16-95.
  - ◊ If the required moment exceeds the flexural design strength, remove the element and redistribute the loads associated with the element per Section 3-2.4.3.

AP Method for Wood

- Combined Axial and Bending Resistance of Wood
  - ◊ The acceptability criteria for combined axial and bending loads is based on the interaction equation provided in Chapter 6 of AF&PA/ASCE 16-95, using the appropriate strength reduction factor Φ, time effect factor λ, and over-strength factor Ω.
  - ◊ If the element violates the criteria, remove the element and redistribute the loads associated with the element per Section 3-2.4.3.

AP Method for Wood

- Shear Resistance of Wood
  - ◊ The acceptability criteria for shear is based on the shear design strength of the cross-section, per Chapter 5 of AF&PA/ASCE 16-95, using the appropriate strength reduction factor Φ, time effect factor λ, and over-strength factor Ω.
  - ◊ If the element violates the criteria, remove the element and redistribute the loads associated with the element per Section 3-2.4.3.

AP Method for Wood

- Connections
  - ◊ Design strengths for connections must be calculated per AF&PA/ASCE 16-95, using the appropriate strength reduction factor Φ, time effect factor λ, and over-strength factor Ω.
  - ◊ If the connection violates the criteria, remove it from the model.
  - ◊ If both connections at the ends of an element fail, remove the element and redistribute the loads associated with the element per Section 3-2.4.3.

AP Method for Wood

- Deformation Limits for Wood
  - ◊ The Deformation Limits are given in Table 7-3.
  - ◊ Note that Table 7-3 does not contain deformation limits for connections; thus, the deformation limits are applied only to the structural elements

AP Method for Wood

Deformation Limits for Wood

	AP for Low LOP		AP for Medium and High LOP	
Component	Ductility (μ)	Rotation, Degrees (θ)	Ductility (μ)	Rotation, Degrees (θ)
Walls	-	5.1	-	2.3
Roofs	-	3.2	-	1.4
Beams	-	3.7	-	1.7
External Columns - Flexural Mode	-	3.7	-	1.7
Internal Columns - Buckling	1.0	2.4	-	-

AP Method for Wood

- Additional Ductility Requirements
  - ◊ For MLOP and HLOP structures, all external ground floor columns and load- bearing walls must be designed such that the shear capacity is greater than the flexural capacity, including compression membrane effects if appropriate.
  - ◊ Methods for calculating the compression membrane effects can be found in Park and Gamble 1999 and UFC 3-340-01.